Resistor-Temperature Conversion

Tesla cryogenic system local application

Wed, May 11, 1994

The TRTD local application supports needs of low temperature measurements for the Tesla superconducting RF laboratory in LAB-2 in the Fermilab village. Four signals are demultiplexed into 16, thermal emf's measured and used to get the resistance of the cold resistors, which are of two types, platinum and carbon. From the resistance, calibration tables are used with linear interpolation to get the temperature in degrees Kelvin. This note describes the methods used to do this.

Parameters layout

The available parameters for TRTD as seen via "Page E" are as follows:

```
(put picture #1 here)
```

The usual enable Bit# argument is followed by MPXDATA, the base channel# of the four multiplexed signals. V^+,ETC is the base channel# of the sixteen V^+, V^-, emf, res istance, and temperature values, altogether 5 sequential "arrays" of 16 channels. The R REF reference resistor channel# specifies the Pt reference resistor. The next channel# holds the Carbon reference resistor value. MPXSEL is the base Bit# of the digital byte used for selecting the four 1-of-4 multiplexer values. The program sequences this byte through values of 00,AA,55,FF on each four successive cycles. The CURRDIR parameter is the base Bit# of the two bits used for controlling the current direction through the Pt and C resistors, respectively. The EMF PER para meter is the number of cycles between measurements of the V^- and emf values, done by reversing the current direction for four cycles to collect these data.

Demultiplexing

Signals from the RTD system are very small, so they are amplified by four-input multiplexed amplifiers. Two-bit select codes are wired to each amplifier. The program operates all four two-bit select codes at once, as they share the same byte of digital output. Data is read from one selection each cycle, which for the LAB-2 facility is 10 Hz. In this way, all 16 channels of data that result are updated every 400 ms.

Thermal emf's

To measure the thermal emf's that result from the conductor leads that connect from room temperature to cold temperatures, it is necessary to reverse the current. Every so often, perhaps every few minutes, the current is reversed and the data collected for the negative direction of current flow. After taking four cycles to accomplish this, the current is returned to the usual positive direction. The formula for the emf is as follows:

$$emf = (V^+ + V^-)/2$$

These emf values are updated every time a new V^- is measured with the current direction negative.

Resistances

The resistors used are of two types, platinum and carbon. The single Pt resistor calibration set of 10 calibration points only. These Pt calibration points are part of the program source and are as follows:

```
(put picture #2 here)
```

The formula for resistance is as follows:

$$R= ((V^{+} - emf)/V^{+}_{ref})*R_{ref}$$

Here V^{+}_{ref} is the voltage across the reference resistor (Pt or C) and R_{ref} the reference resistor value itself. The reference values are constants in the program. The values at the time of this writing are R_{ref} = 99.82 (Pt) and 1000.0 (C).

The carbon resistors calibration curve is very nonlinear, so more calibration points are used. Linear interpolation is done with 20 calibration points between the *log* of the temperature and the *log* of the resistance. In order to collect these calibration data for use by the TRTD program, the calibration data points were entered into Excel by editing the original full calibration data set text file. In the spreadsheet, it was easy to calculate an average of the 5 calibrated carbon resistors for use with those carbon resistors that have no measured calibration data. In addition, logs were calculated for the temperature and resistance calibration data points. These log values were output from Excel via a text file, which was then edited into an MPW assembly source file containing "DC.S" data directives. This source file was then assembled and the resulting data downloaded into the station that will run the TRTD local application. Upon initialization, the program requests this local data file and places the data into its calibration data arrays for use in converting the carbon resistances into temperatures. Part of the calibration data entered into Excel was this:

```
(put picture #3 here)
```

The calculated logs of the calibration point data are as follows:

```
(put picture #4 here)
```

These data were then edited as data declaration statements into an MPW assembly source file, assembled and downloaded as a data file of 32-bit floating point values called DATATRTD into the local station along with the LOOPTRTD local application. When the program is first initialized, it reads the data file for use during Carbon resistor temperature conversion.

Internal details

Four channels are read each cycle and converted as necessary. Of the 16 channels read, they are of the following "resistor types":

(put picture #5 here)

The resistor type specifies which reference resistor is used as well as which calibration data to use to perform the temperature conversion.

During program operation, a data structure allocated at initialization keeps track of the context. Using Page E, one can find the location of this dynamically assigned data structure. Its structure at the time of this writing, expressed in the format produced by the memory dump page application, at a time when the signal values may not have been valid, is as follows:

```
(put picture #6 here)
```

The diagnostic `deltaTimes` byte array shows elapsed times per 10 Hz cycle in units of 0.5 ms. (A value of 02 means 1 ms.) Since the program operates on 4 signals per cycle, these times exhibit a periodicity of four cycles.

All floating point values are in IEEE standard 32-bit single precision.

Debug mode

A special debug mode is available for checking the ohms to temperature conversion for the Carbon resistors. To use it, find the above structure using Page E. Then set the debug#, which is initialized to zero, to the index value 1–16 of the channel whose conversion is to be checked. When this word is nonzero in this range, the program stops doing its usual work and concentrates on only the given channel index. It accepts the resistance value from the resistance channel, rather than computing a new one based upon the current demultiplexed data readings. This allows a value to be set into a resistance channel and the temperature channel observed resulting from this conversion. One can make a calibration plot of temperature versus resistance in this way using, for example, the Parameter Page on the Macintosh written by Bob Peters. Here is an example of making such a calibration curve for the T6 signal:

(put picture #7 here)

Logarithms, etc

Because of the extremely nonlinear characteristic of the resistance of the Carbon resistors relative to temperature, it was necessary to work with logarithms of these parameters. With linear interpolation on the *logarithms*, reasonably accurate results can be obtained. But the IRMs use a 68040 cpu, which does not have support for logarithms and powers on-chip, although it does have support for the basic add, subtract, multiply and divide. So a routine was needed to compute logarithms and powers. In a book called "Approximations for Digital Computers" by Cecil Hastings, Jr., Princeton University Press, 1955, can be found suitable formulae for these and other functions to several degrees of accuracy. The formula for $\mathrm{Log}_{10}(x)$ that was used in TRTD has an error function < 0.000002 over the range $1 \leq x \leq 10$. Its form is as follows:

(put picture #8 here)